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Long-Term Monitoring for Aquatic Effects of Acidic Deposition: An Approach to Considering Regional Aspects of Information from Existing Monitoring Sites (Workshop Proceedings)

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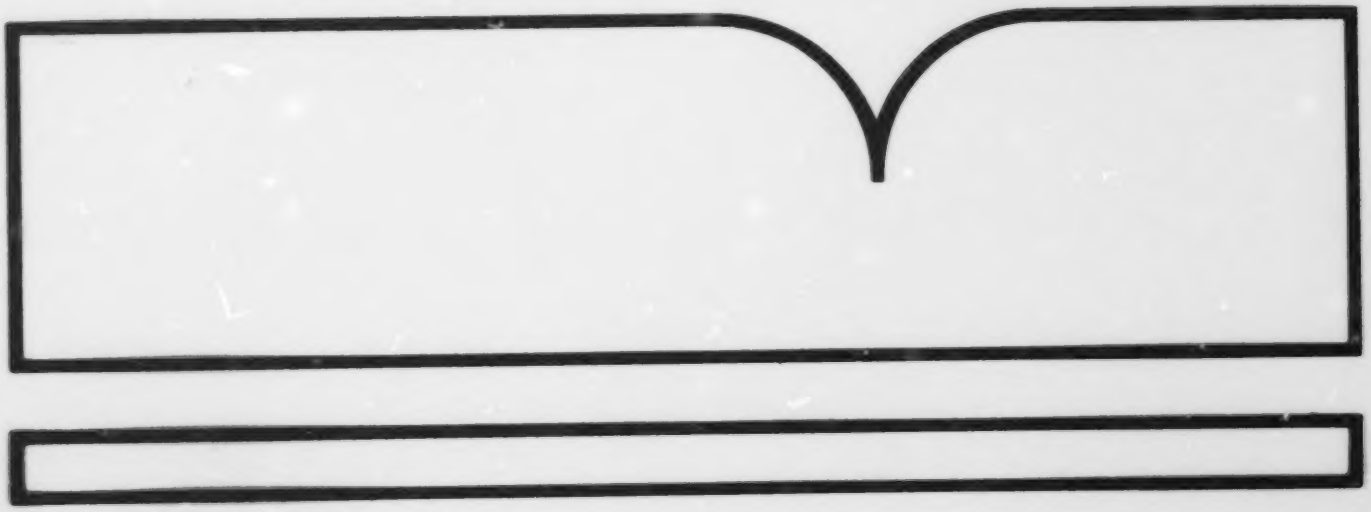

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INTRODUCTION

In 1983, the United States Environmental Protection Agency (EPA) initiated the Long-Term Monitoring (LTM) Project in cooperation with other federal and state agencies and university researchers. The purpose of the LTM Project was to obtain data on long-term trends in water chemistry for acid-sensitive systems across a gradient of sulfate deposition.

Unless the design of a monitoring network is embedded in a statistically representative survey of resources, it is not possible to extrapolate quantitatively from trends found at individual monitoring sites to trends in the resource as a whole. Most modern monitoring networks address this issue by choosing sites believed to represent broad classes of site types, even if quantitative data on the status and extent of resources are lacking. In some cases, as with the LTM Project, quantitative data on the status and extent of resources does not become available until after the network design has been implemented. In these cases, it is useful to create a model relating the monitoring sites to the survey design, in order to make quantitative or semi-quantitative statements regarding the implications of trends found in the monitoring network for the resource as a whole.

In this paper we briefly describe the LTM network and the major early (6-year) findings from this network, and discuss one conceptual approach to relating LTM monitoring sites to EPA's statistically representative National Surface Water Survey (NSWS).

DESCRIPTION OF THE LTM NETWORK

The LTM Project (Newell et al. 1987) was designed to function as an early warning network to identify emerging trends in strategically located low acid neutralizing capacity (ANC) surface waters of the United States. The current network includes 86 sites (Figure 1, Table 1) of which 75 are lakes; the remainder are streams in the Adirondack and Catskill mountains of New York. Sites in the network lie across a gradient of wet sulfate deposition ranging from greater than 3 g $m^{-2}y^{-1}$ in the Adirondack and Catskill mountains to less than 1 g $m^{-2}y^{-1}$ at high-elevation lakes in the Colorado Rocky Mountains.

EARLY (6-YEAR) LTM FINDINGS

Data validation and analysis is complete for LTM network sites in the Adirondacks, Maine, and Upper Midwest through 1988. Major findings over the 6-year period of record include (1) a general decrease in sulfate concentrations (2-5 $\mu eq\ L^{-1}y^{-1}$) in many Adirondack and Maine sites, (2) some decreases in ANC (2-5 $\mu eq\ L^{-1}y^{-1}$) in the Adirondacks and Upper Midwest, and (3) increases in ANC (2-3 $\mu eq\ L^{-1}y^{-1}$) at the coastal Maine sites, possibly related to increasing sodium concentrations. A fuller description of both the LTM network and the early results can be found in Ford et al. (in preparation).

RELATIONSHIP BETWEEN THE LTM AND THE NSWS

In this section, we present elements of one approach to interpreting results from the LTM network in a regional context. In this approach, we interpret observed trends at LTM sites and groups of sites in the context of the National Surface Water Survey (NSWS) of low ANC surface waters of the United States. The NSWS (Landers et al. 1988, Eilers et al. 1988, Kaufmann et al. 1988) was designed to produce a region-specific probability sample of the population of resources at risk.

The relationship between LTM sites and NSWS sites can be described for single variables by plotting the position of LTM sites on cumulative frequency distribution (CFD) functions for specific NSWS subregions (sensu Landers et al. 1988) and chemical variables of interest (Newell et al. 1987) (Figure 2). This analysis requires that monitoring sites conform to the constraints of the target population for which the CFDs are given. In this example, the primary constraint is that all monitoring sites must be greater than 4 ha, since the Eastern Lake Survey portion of the NSWS only considered lakes > 4 ha.

Figure 2 considers the case for ANC in three subregions of the Upper Midwest. In these diagrams, the curves reflect the distribution of sites as given by the NSWS, and the squares represent individual LTM monitoring sites, located on the ANC curve. The values for the LTM sites were determined during the NSWS, for which the LTM sites were sampled as "Special Interest" sites (Linthurst et al. 1986). According to Figure 2, (1) the NSWS distribution of low ANC sites varies across the three subregions, and (2) the range of LTM sites in these three regions provides generally good coverage of the lower part of the ANC range for two of the three subregions.

This is useful information. However, there are many different types of lakes in the Upper Midwest, and this approach does not give any insight as to how heterogeneous the lake resource really is or how well represented any particular type of lake might be. In order to assess heterogeneity, that is, to quantitatively describe populations of lakes, a multivariate approach must be adopted. Once the populations have been identified, some will undoubtedly be of greater interest for monitoring purposes than others. Thus, our approach (Young and Ford 1989) focuses on creating objective definitions of both these terms (Figure 3).

Interest has been defined in two-dimensional space using titration-based chemical models involving buffer intensity and ion ratios for assessment of (1) the chemical sensitivity of lakes to acid or base additions, and (2) the lake response to past acid loadings. Briefly, the "Sensitivity" (S) axis is buffer intensity ($-dC_A/dpH$), and the "Response" (R) axis is the ratio of the sum of acidic anions to the sum of base cations, in equivalents (pC_B-pC_A). A general explanation of the rationale behind the creation of these axes can be found in Young and Ford (1989), and a detailed description of the derivation of the axis definitions can be found in Young (submitted).

We refer to the various applications of the two-dimensional space defined by the axes "Sensitivity" and "Response" as "S/R plots". An S/R plot for Upper Midwest lakes of the NSWS, including LTM lakes, is given in Figure 4. Sensitivity increases along the Y-axis, and response to past acid loadings, measured as the increase in the ratio of acidic anions to base cations, increases along the X-axis. The vertical line indicates completion of the "titration" of base cations by acidic anions ($pC_B = pC_A$). Sites that plot to the right of this line are interpreted to be currently acidic, possibly increasingly so, from acidic deposition. The highest sensitivity sites occur near this R = 0 line. These sites are poised between two arrays of lower sensitivity sites, those buffered by the bicarbonate buffer system that plot to the left of this line, and those buffered by aluminum and organic complexes that plot to the right of this line. Fig. 4 indicates that the LTM sites cover a range of both sensitivity and response to acidic deposition, but primarily the high sensitivity/high response portion of S/R space.

Standard multivariate techniques were used to create an example set of lake subpopulations (in this case, clusters) to illustrate elements of an approach in which LTM lakes can be related to the NSWS statistical sample. Based on 24 physical and chemical variables, 5 principal components with eigenvalues ≥ 1.0 were extracted from the Upper Midwest NSWS lakes, and the highest loading variable on each component was retained for an unweighted, non parametric cluster analysis of both NSWS and LTM lakes. The results of the cluster analysis are shown in Figure 5, in which cluster (lake subpopulation) means are plotted on S/R axes using circles with diameters proportional to lake subpopulation size (smallest circles are single lakes). Also, each multi-membered lake subpopulation is annotated to show the nature of trends observed in included LTM lakes. It is reasonably clear from the patterns noted in Figure 5 that the lake chemical trend characteristics (changes in ANC and SO_4^{2-}) of the subpopulations are consistent with their S/R values.

The elements of the approach presented here do not take into account population weighting factors or provide an objective a posteriori assignment of LTM lakes into NSWS subpopulations. These refinements are necessary elements of a complete procedure for casting the LTM sites into the NSWS statistical sample with confidence. Still, the techniques illustrated here suggest that it is possible to fit information obtained from individual monitoring sites into a regional framework created later in time, and that the results obtained from this procedure can be quite useful.

SUMMARY

Monitoring networks are often designed without regard for the question of how to quantitatively interpret trends in individual network sites with respect to probable changes in the actual populations of similar resources in given geographic areas of interest. As a result, the question of how many other resources could be expected to respond similarly to the monitored site(s) cannot usually be addressed. The U.S. EPA created the NSWS to determine the national status and extent of low ANC, acid-sensitive surface waters. This paper has explored elements of one conceptual approach designed to relate individual monitoring sites that were not part of the original NSWS probability sample back to that sample, and hence back to the entire population of similar resources.

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TABLE 1. EPA'S LONG-TERM MONITORING (LTM) PROJECT

Location	Principal Investigator	Affiliation	Number of sites	Period of Record	Sampling Schedule	Comments
Adirondacks, (New York)	Charles Driscoll	Syracuse U.	15 lakes	Spring 1985	Monthly	Historical data, sampled monthly, from 1982-1984 [1].
Vermont	Wallace McLean Doug Burnham Jim Kellogg	Vermont Agency of Environmental Conservation	24 lakes	Winter 1981	Seasonal	Sampling and analytical changes (SO_4) occurred in spring 1985.
Maine	Terry Haines Steve Kahl	USFWS; U. of Maine	5 lakes	Fall 1982	Spring, summer, fall	
Upper Midwest	Patrick Brezonik Katherine Webster	U. of Minnesota; Wisconsin Dept. of Natural Resources				Historical data, sampled sporadically on a seasonal basis, from 1978 to 1983 [2].
(Minnesota)			4 lakes	Fall 1983	Spring, summer, fall	
(Wisconsin)			13 lakes	Fall 1983		
(Michigan)			11 lakes	Fall 1983		
Rocky Mountains, (Colorado)	John Turk	USGS, Denver	10 lakes	Summer 1985	Monthly in summer	
Catskills (New York)	Pete Murdoch	USGS, Albany	4 streams	Fall 1983	9 times per year	Sampling is flow directed

[1] Two years of additional data collected for most of these lakes between 1982 and 1985 by Syracuse University were funded by the Electric Power Research Institute during the Regional Integrated Lake Watershed Acidification Study (Driscoll, pers. comm). Sampling for most lakes is done at or along outlets, to maintain consistency with the pre-existing RILWAS data set.

[2] Data collected by the University of Minnesota-Duluth and the Wisconsin Department of Natural Resources through a cooperative agreement with the Environmental Research Laboratory, Duluth, are available for most of these lakes for the period 1978-1982 (Glass, pers. comm). The sampling schedule for these lakes was variable, ranging from twice a year to seasonally, and included multiple samples per lake.

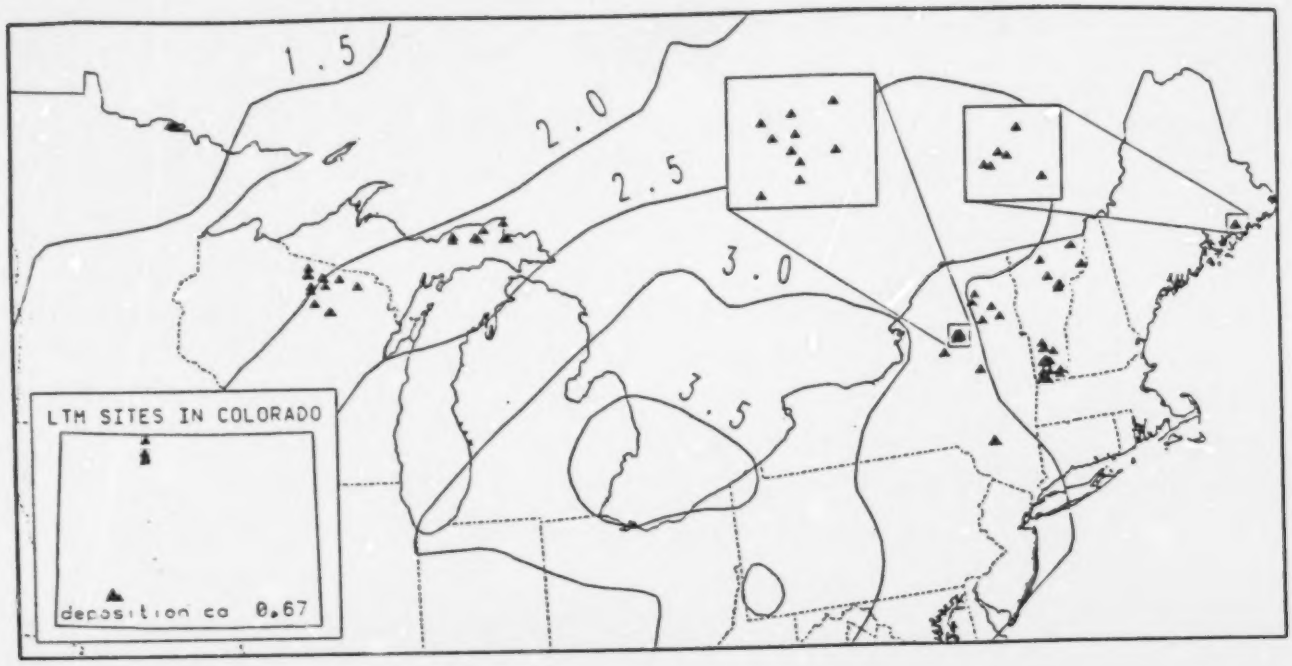

Figure 1. Current configuration of the Long-Term Monitoring Project network, mapped against 1980-1984 composite isopleths of wet sulfate deposition (g m^{-2} y^{-1}) (Barchet 1987). Isopleths are given only for the eastern U.S.; Colorado deposition estimate is based on the 1984-1987 record at the Buffalo Pass NADP station. Data from this high elevation station do not meet NADP completeness criteria due to sampling difficulties, and thus must be regarded only as estimates.

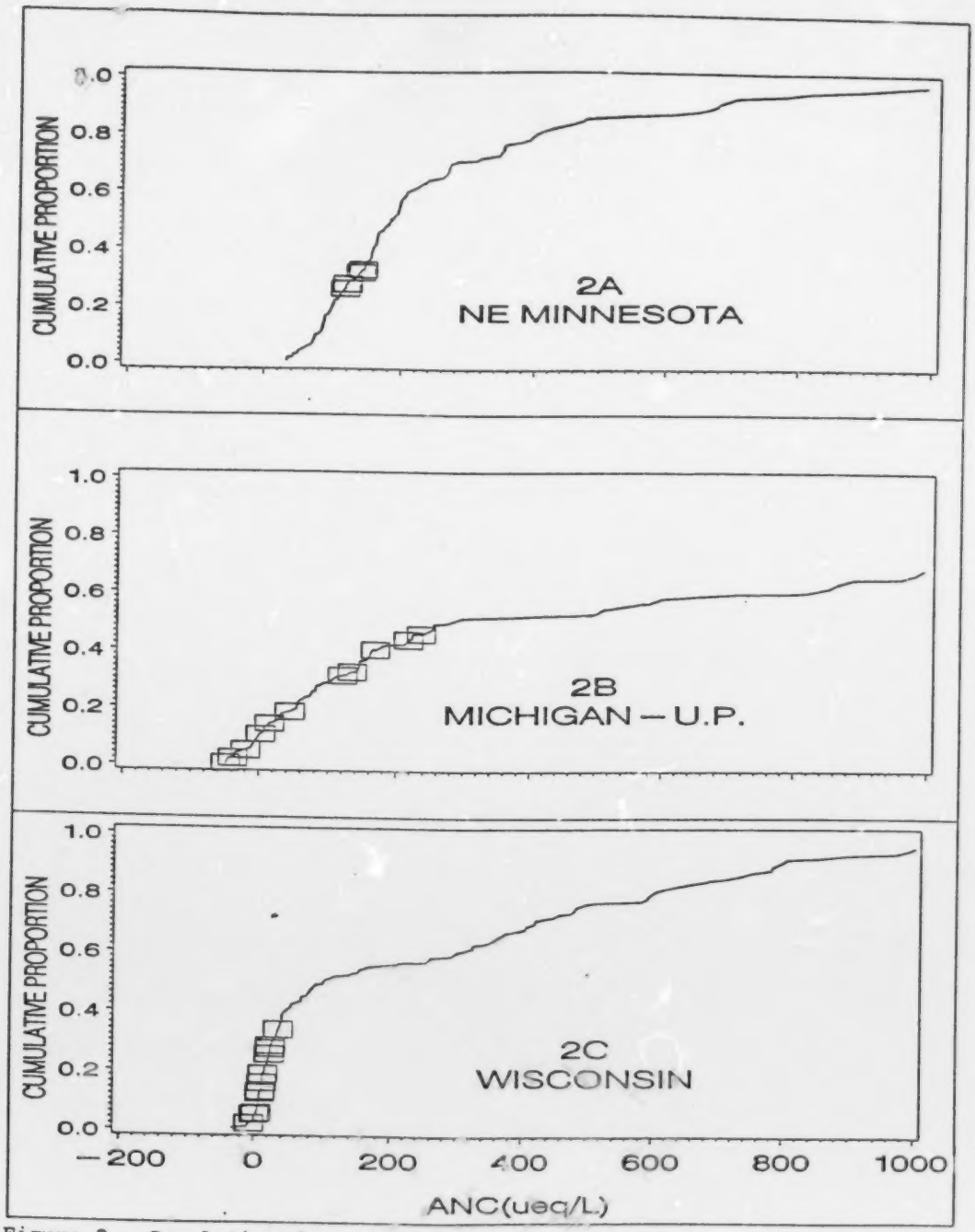

Figure 2. Cumulative frequency distributions (CDFs) for acid neutralizing capacity (ANC) in three NSWS subregions (Landers et al. 1988) of the Upper Midwest. Approximate percentages of sites below any given ANC value can be determined from such distributions. The differences in the shape of the CDFs for the three subregions reflects subregional differences in water chemistry. Centroids of boxes indicate specific values for individual LTM sites in the given subregion sampled during the NSWS (updated from Newell et al. 1987).

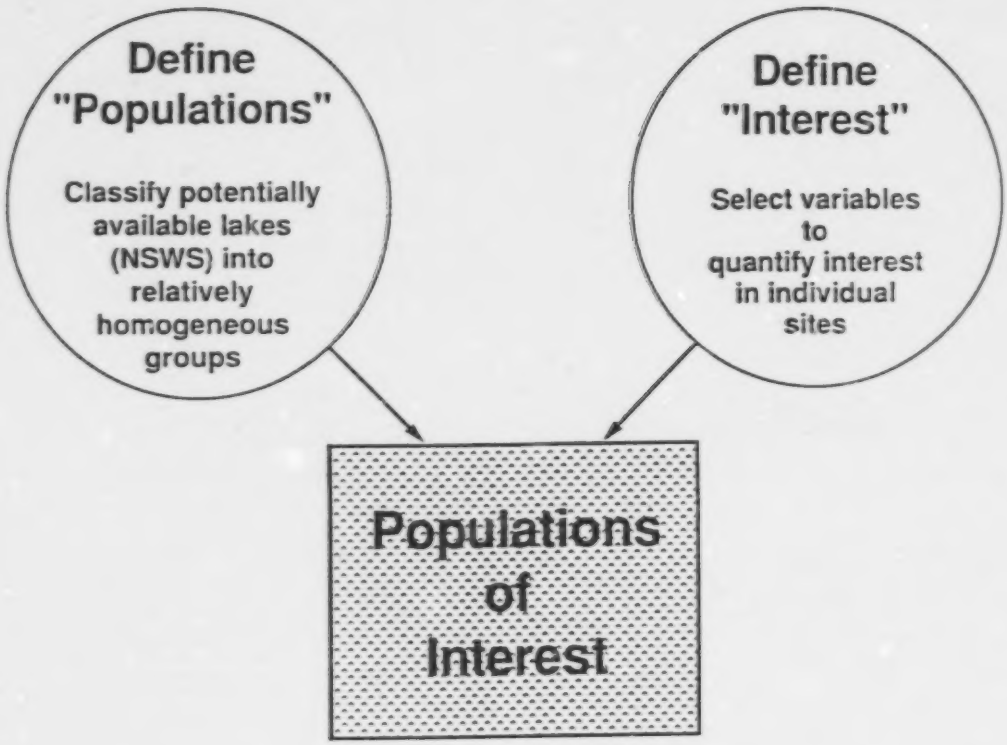

Figure 3. Defining "(Sub)populations of interest".

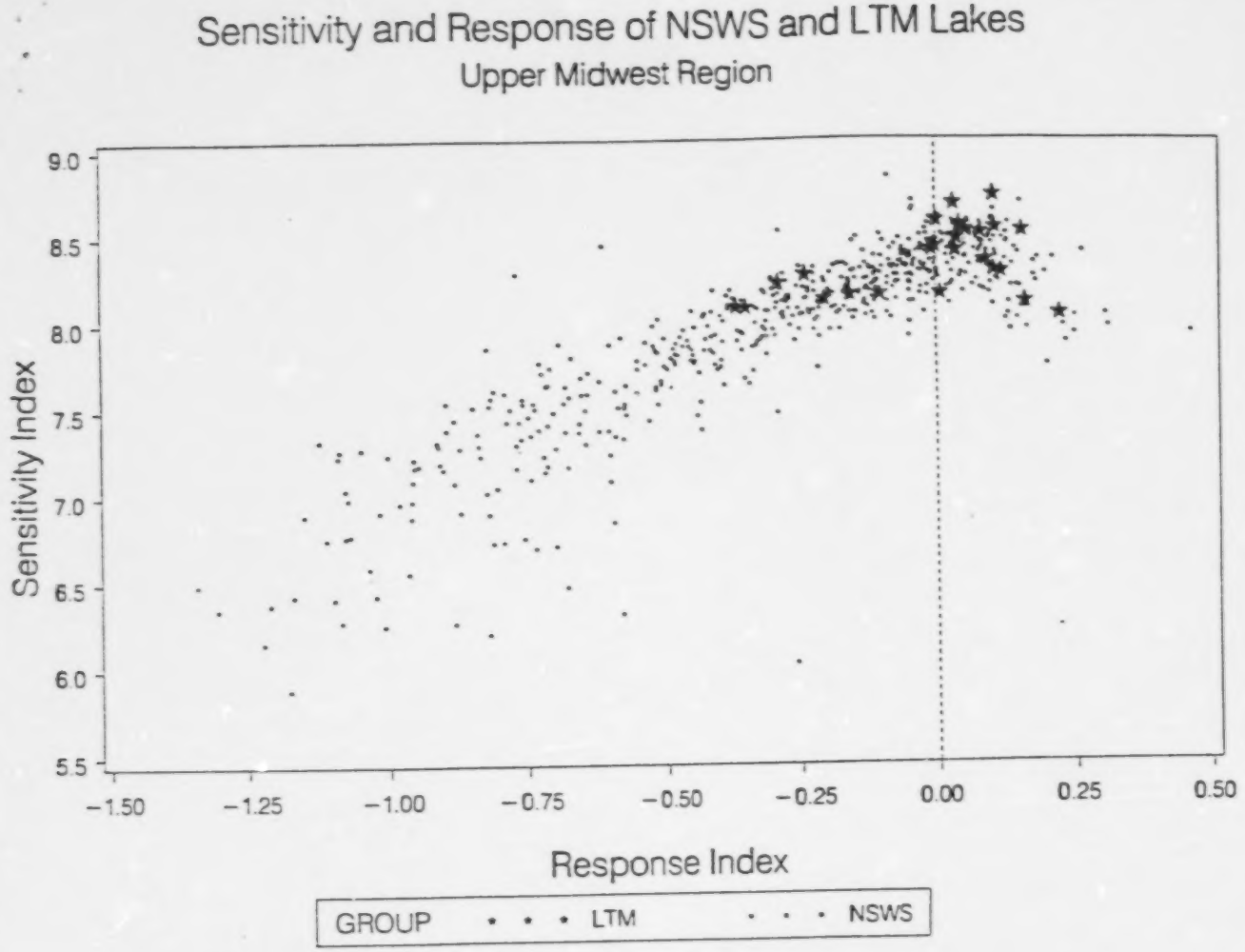

Figure 4. National Surface Water Survey (dots) and Long-Term Monitoring (stars) sites of the Upepr Midwest, plotted in S/R space. See text for discussion.

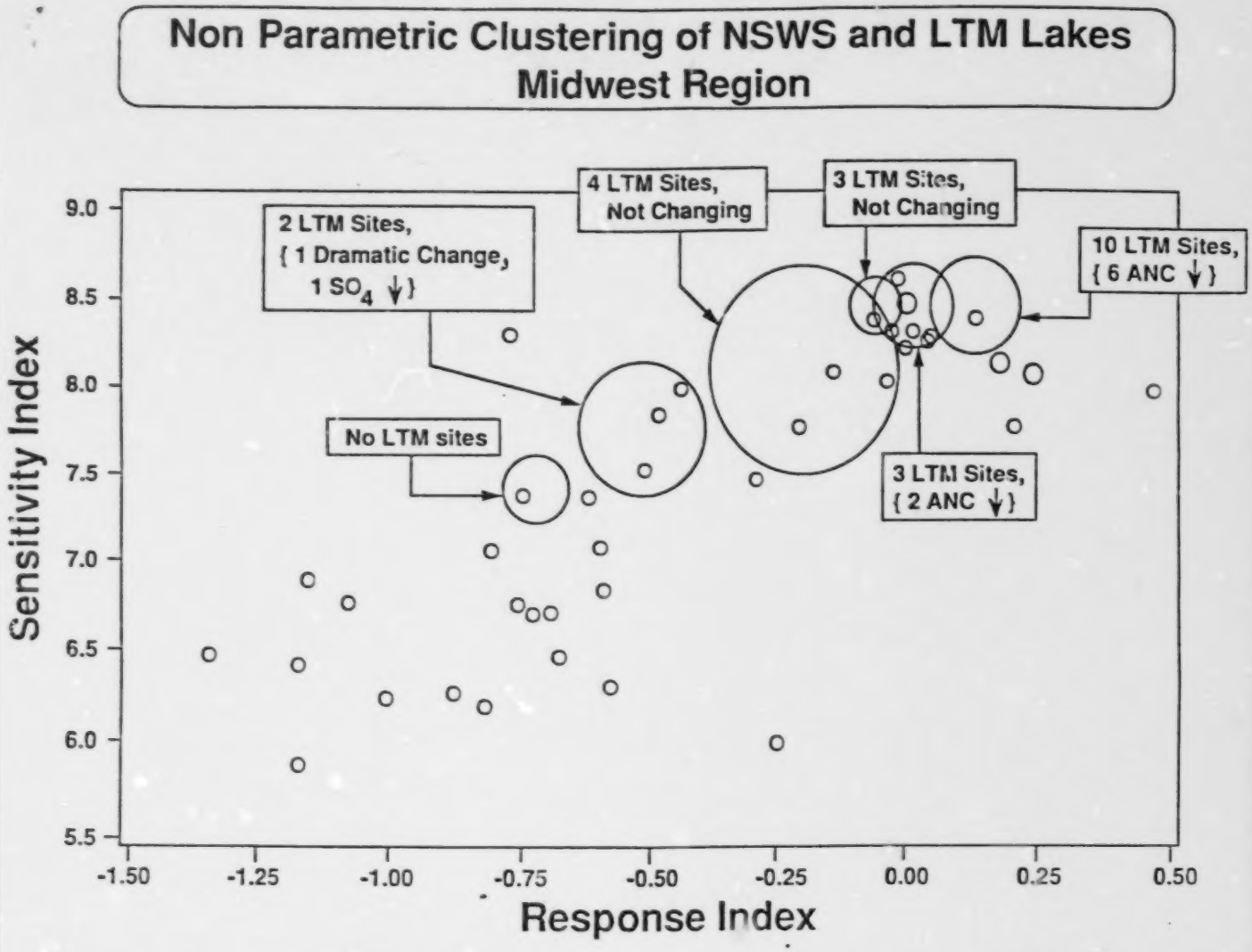

Figure 5. Multivariate analysis of Upper Midwest NSWS and LTM sites, plotted in S/R space. Circles represent individual clusters, with the size of the circle proportional to the number of sites included as cluster members. The smallest circles are clusters of one. Position of the circles reflects position of cluster centroids in S/R space.